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SOLAR-PLANETARY-CLIMATE STRESS, EARTHQUAKES AND VOLCANISM

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ABSTRACT

The largest volcanic eruptions since AD 1800 correlate with periods of enhanced seismicity, changes in the earth's spin rate, and the Chandler wobble. Furthermore, a marked increase in the number of major eruptions apparently occurred during the Maunder Sunspot Minimum (1645-1715) at a time when global temperatures were depressed. Solar activity might trigger volcanism through solar-induced climate change which could lead to variations in global spin rate and hence to increased crustal stresses and seismic and volcanic potential. Such solar activity may be modulated by planetary tidal effects which might additionally lead to enhanced crustal stress through direct influence on the earth's axial tilt, wobble and rate of rotation.

Volcanic dust veils have often been suggested as a cause of periods of global cooling. While it has now been confirmed that some major historic volcanic eruptions have been followed by 0.2°C to 0.5°C decreases in global or hemispheric mean temperature, several studies have demonstrated that volcanically induced cooling usually lasts for less than 5 years.[1,2] Therefore, even large explosive volcanic eruptions seem unlikely to cause cooling trends of decadal or longer length. In a recent study,[3] we have found that many large explosive eruptions have been associated with such long-term cooling, but that, within the limits of dating, the cooling trends often began before the explosive eruptions. It is thus possible that rapid climatic cooling may in some way trigger volcanic eruptions, or alternatively that such coolings and volcanic eruptions may be linked through common causal mechanisms. We have therefore pursued the question further to explore the possible connections between volcanic activity and climate, and to search for common underlying causes of the two phenomena.

Several workers have noted an apparent correlation between earth tidal stress and seismic and volcanic activity.[4-6] Roosen and others[7] have found a significant correlation between earth tidal stresses and northern hemisphere temperatures. They suggest that variations in tidal stresses on the earth caused by the Sun and Moon trigger volcanic eruptions. Changes in stratospheric dust loading are proposed to cause the related decreases in surface temperatures.

Lambeck and Cazenave[8] find a further correlation between climate changes and length-of-day (global spin rate), and believe that these two factors have a common origin - increased seismicity and frequency of volcanic eruptions. In their suggested scenario, increased volcanic activity leads to climatic changes which in turn cause fluctuations in global spin rate. The increased earthquake activity associated with the volcanicity further contributes to the changes in spin rate.

However, as noted above, recent studies have shown that it is unlikely that volcanic perturbations of the aerosol layer can directly cause climatic cooling of decadal or longer length, and that many past cooling trends actually began prior to large volcanic eruptions.[1] Furthermore, these cooling trends often coincided with changes in the geomagnetic field[9-11], and/or changes in solar activity[1,12] which have been cited as possible causes for the coolings.

Lambeck and Cazenave[8] note that their "meteorological excitation function" lags behind spin-rate changes by about 15 years, and further that changes in mean global surface temperature lag behind spin-rate changes by about 10 years. Thus, it is difficult to see how the climatologic parameters could be the direct cause of the variations in global spin rate. Spin rate and climate change may however, be linked to a common causal mechanism.

Seismic-activity variations are in phase with changes in the earth's rate of rotation[13], and therefore a case can be made for suggesting that changes in spin rate affect seismic activity through changes in the crustal stress field. These same changes in crustal stress, perhaps, could lead eventually to increases in explosive volcanism.

Accordingly, we have plotted the largest volcanic eruptions since 1800[14] along with seismic activity, changes in global spin rate, and the Chandler wobble[13]. We note a good correlation between periods of enhanced seismicity and volcanicity but that peaks of volcanic activity tend to lag behind the increases in seismic activity by about 10 to 15 years (Fig. 1). Although initiation of new cycles is simultaneous, the lag effect in volcanism is to be expected because of feedback due to self-perpetuating crustal disturbances. In this way, the volcanic activity may well be ultimately mobilized by the crustal stresses resulting from changes in planetary rotation rate and tilt.

Other causal relationships are observed. It has already been suggested that such increases in volcanic activity and seismicity might be linked to variations in solar activity[15,16]. As long ago as 1914, Köppen[17] proposed a correlation between air temperatures, sunspots and volcanic activity. Simpson[18] correlated a 1950-1963 series of earthquakes with high sunspot levels, but skewed to show a 2-3 year delay. Machado[19] reported both the 11 and 22-year solar cycles in the long term records of Azores earthquakes and proposed a plate-tectonic coupling.

It has also been proposed that changes in global spin rate are related to solar activity. Spin rate varies seasonally as a result of changes in atmospheric circulation.[8] Besides simply the atmospheric wind-friction effect, there is evidently also a solar-wind (magnetic) input. Thus, after the great solar storm of August 1972, there was an immediate spin-rate response.[20]

Longer term changes in spin-rate might also be a result of meteorological variations that are tied to changes in solar activity[15,20]. Within the period of instrumental observations, Challinor[16] showed a sunspot/spin rate/earthquake correlation for one solar cycle. Anderson[13] has extended this back to AD 1800 showing a striking correlation between spin rate (length of day) and seismic energy developed in the earth's crust (Fig. 1). Increase in the Chandler wobble following such spin-rate accelerations has also been observed.

In order to test for a correlation between long-term fluctuations in solar activity, volcanism, and climate we have compared, over a historical period of 475 years, the periodicity of major reported explosive volcanic eruptions[14] with solar activity (using decadal peaks of the Zürich sunspot numbers and extending them back to AD 1500 with the use of the Schove auroral transfers)[22], and climate as interpreted from the oxygen-isotope record of the Camp Century, Greenland ice core[24] (Fig. 2).

A good correlation exists between the long-term smoothing of the sunspot cycle, and Greenland temperatures - with cool temperatures corresponding to long-term sunspot minima[12]. We note that the numbers of reported volcanic eruptions show a marked increased during the Maunder Sunspot Minimum (1645-1715), including a number of large eruptions that produced stratospheric dust veils. The number of reported volcanic eruptions decreased coincident with increasing sunspot numbers in the late 1700's, rose again with the low sunspot numbers at around 1800, and then continued to rise through the late 1800's and 1900's.

Within the general increasing trend, from the late 19th century through the 20th century, there is a decrease in reported volcanic eruptions from 1890 to about 1910, another sharp decrease in the 1920's, with high numbers of volcanic eruptions after about 1950.

We recognize that there are problems in using the record of reported volcanic eruptions as a measure of past global volcanic intensity. Many volcanic eruptions occur in remote areas where reporting in the early days may have been erratic and/or episodic. It may be argued that the general rise in the number of reported eruptions from AD 1500 to AD 1700 coincides with the period of European exploration and colonization of geographically remote areas. The increase in reported eruptions would therefore correspond to the influx of European observers into volcanically active regions. In order to minimize the possible reporting bias, we have plotted only the largest eruptions - classes 3 to 5 of Newhall and Self[14]. Such explosive eruptions would most likely affect wide areas, and be noted by even casual observers. These eruptions certainly contributed to stratospheric aerosol loading.

The rise in volcanic eruptions from 1500 to 1700 should not be automatically attributed to increased reporting, because this would fail to explain the significant decrease in the numbers of large eruptions in the 18th through the early 19th century. The last two decades of the 17th century were five times higher than those of the mid-18th century. No apparent historical decrease in observers or breakdown in communication occurred during this period.

The opposite, however, may be true for the late 19th century. The general increase in the numbers of reported eruptions beginning in the 1880's (triggered especially by the Krakatau experience of 1883) is likely to be in part a result of the establishment of more systematic scientific observations on a global basis. Nevertheless, times of significantly lower numbers of reported volcanic eruptions within this later period are difficult to explain as artifacts of reporting bias. It is notable that these periods of decreased reporting of the largest volcanic eruptions in the 20th century do not correspond to the decades of World War I (1910-1920) or World War II (1940-1950), when a drop in reporting might be expected[26].

As noted above, causal links between seismic and volcanic activity on one hand, and variations in solar activity, global spin rate and tidal stress on the other have been suggested before. Long-term changes in solar activity, as exemplified by the envelope of sunspot maxima and minima, have been convincingly shown to have had an effect on global climate on time scales of tens to hundreds of years[12,27]. The long-term solar cycle may be modulated by planetary dynamics[28-30].

Several workers have suggested that the sun displays a 179 to 180 year cycle in numbers of sunspots and solar activity. Such a cycle is suggested by the planetary theory of sunspots. This period coincides with the times when all of the planets come to be on the same side of the sun[29]. Jose[28] offered the variations in motion of the sun about the barycenter (center of mass) of the solar system as the cause of the cyclic sunspot variations, whereas Cohen and Lintz[31] attributed the 179 year cycle of solar variations to a beat phenomenon of the 11 and 9.8 year periods. Such a ∿180-year cycle along with a 360-year cycle have been reported in several climate records such as Greenland ice cores[24], beach-ridge cycles[32], tree rings[33], and other indicators, and has been traced back into the geological record[34].

A time period of 178 years corresponds to 16 "sidereal years" of the sun (moving around the barycenter of the solar system), and likewise to 15 "sidereal years" of Jupiter[35]; at these intervals the sun is gravitationally displaced from the barycenter by more than one solar diameter[28]; the solar "orbit" around this barycenter has a radius that theoretically may exceed 1.5 million km. Although the tide-raising force of the planets on the sun is 10^5 less than that of the sun on the earth, the solar photosphere is vastly more susceptible to the resonance and inertial effects. It is such tidal forces which have been proposed to modulate solar activity[30,36].

On a long-term basis, it seems likely that solar activity might trigger volcanism through solar-induced climatic changes which could lead to variations in planetary spin rate and hence to increased crustal stress and seismic and volcanic potential. Furthermore, the changes in solar activity and in the earth's crustal stress may both be independent results of common planetary tidal parameters. The same planetary configurations that appear to modulate solar activity might lead to variations in the earth's axial tilt, wobble, and/or spin rate[37], which have climatic correlations. These variations would in turn lead to enhanced crustal stress. Therefore, the planetary influence on crustal stress in the earth may come both from solar-induced meteorological effects on spin rate and axial tilt[38] and through direct planetary tidal effects on the earth's rotation and tilt.

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FIGURE CAPTIONS

Figure 1 Changes in rotation rate of the earth ($\Delta\omega/\omega$), Chandler Wobble amplitudes, 10-year means of earthquake energy (E_s) (after Anderson[13]), and 10-year means of numbers of reported major volcanic eruptions (classes 3 to 5 of Newhall and Self[14]). Some major explosive eruptions that produced significant stratospheric aerosol contributions are labelled.

Figure 2 (a) Numbers of reported major volcanic eruptions (classes 3 to 5 of Newhall and Self[14]). Also plotted are decades of greatest dust-veil indices for the northern hemisphere (after Lamb[21]), and time of some major destructive historical earthquakes. (b) Decadal maxima of Zürich sunspot numbers, extended back before AD 1620 using reported auroral observations[22]. Times of peak auroral activity are plotted after Bray[23]. (c) Record of δO^{18} in the Camp Century, Greenland ice core. Low δO^{18} values are inferred as indicating greater northern hemisphere temperatures[24]. Solid curves on graphs a, b and c are plots of 50-year means. (d) Cycles of 90 years, 180 years, and 360 years. Projected back from 1989, the next key year in Stacey's[25] "Zero-check cycle" of all-planetary conjunction. This 556-year period equals the precession of the lunar perigee and thus the earth's maximum perigee spring tides; it equals 50 times the 11.1 year sunspot cycle. The last major incidence of the all-planet cycle was AD 1433.

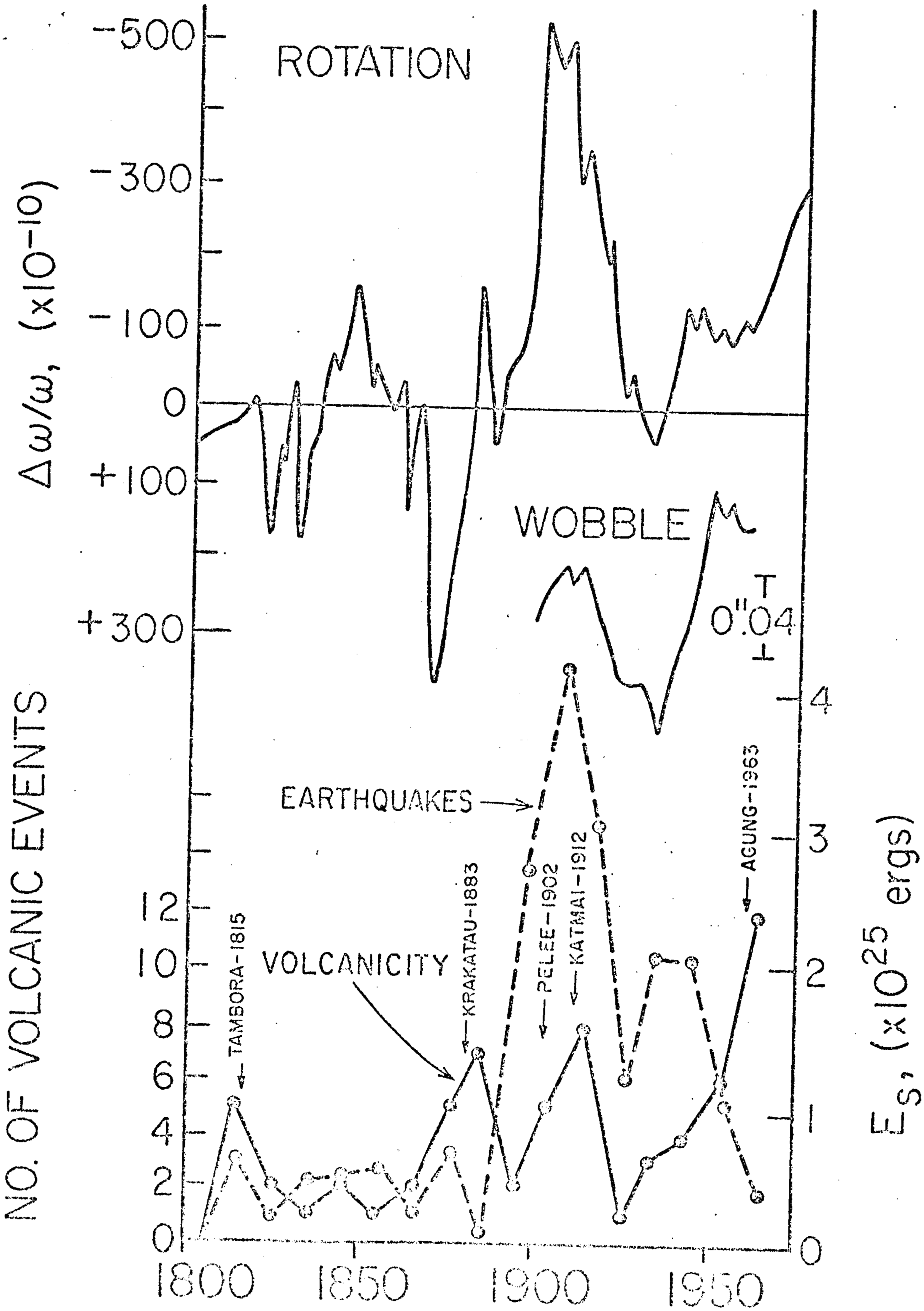
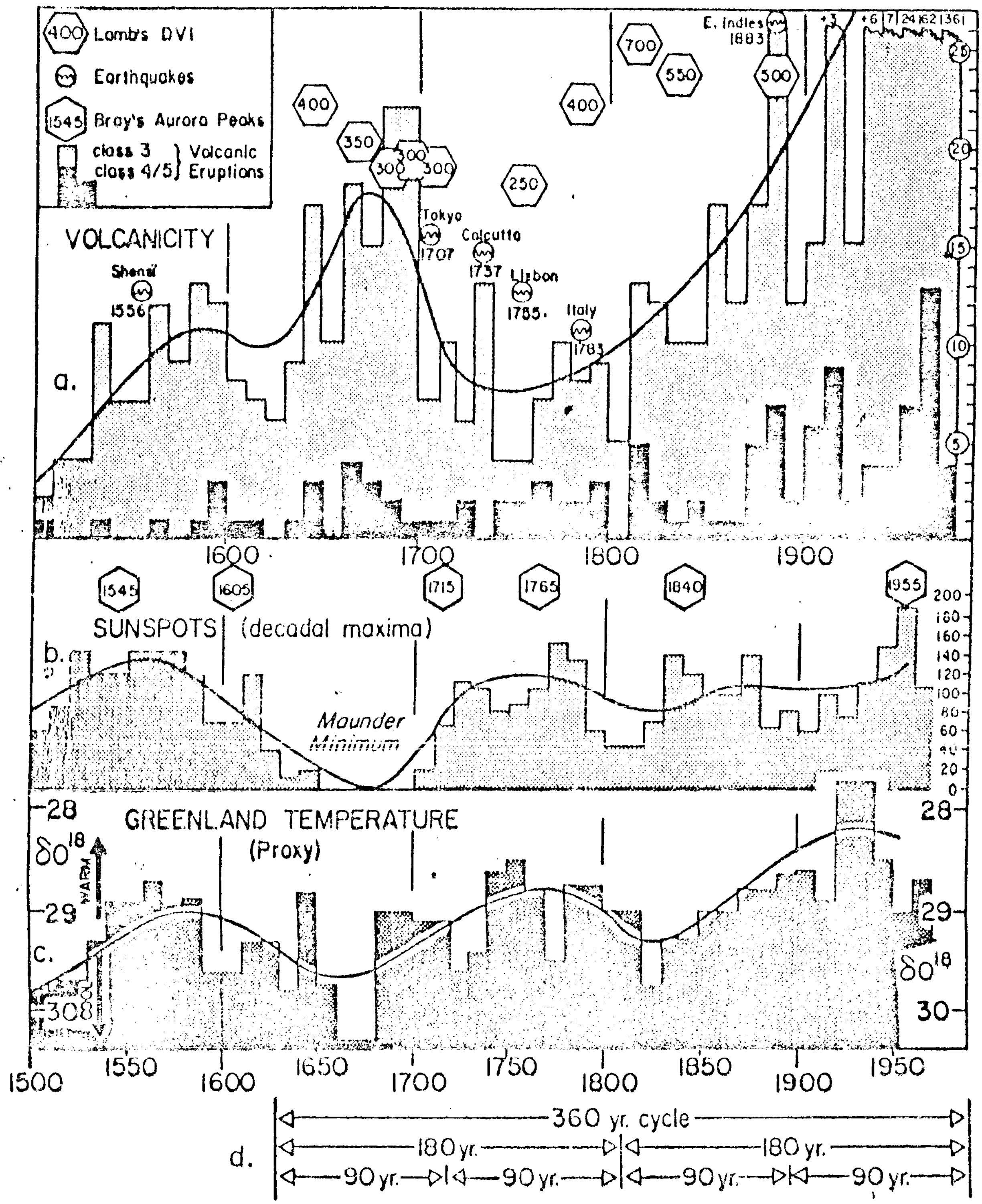

ROTATION
$\Delta\omega/\omega$, ($\times 10^{-10}$)
-500
-300
-100
0
+100
+300
WOBBLE
0".04
EARTHQUAKES
VOLCANICITY
NO. OF VOLCANIC EVENTS
E_S, ($\times 10^{25}$ ergs)
TAMBORA-1815
KRAKATAU-1883
PELEE-1902
KATMAI-1912
AGUNG-1963
0
2
4
6
8
10
12
1
2
3
4
1800
1850
1900
1950

Figure 1



Lamb's DVI
Earthquakes
Bray's Aurora Peaks
class 3 } Volcanic
class 4/5 } Eruptions
VOLCANICITY
a.
SUNSPOTS (decadal maxima)
b.
Maunder Minimum
GREENLAND TEMPERATURE (Proxy)
c.
d.
360 yr. cycle
180 yr.
90 yr.

Figure 2